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Predicting Output Power of Wind Turbines using Adaptive Neuro-Fuzzy Inference System to Improve Practical Adjustment of Turbine Blade Angle

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ABSTRACT

In this paper, a new model is presented for predicting the output power of wind turbines. In this model which uses the modified method of adaptive neuro-fuzzy inference system, generator torque, turbine blade angle, wind speed and output power in its two past time are defined as the system input and the system output is the predicted output power of turbine which is used to improve the practical adjustment of turbine blade angle. The proposed model has been used in a wind farm including three 3-MW turbines with double fed induction generators (DFIG). Comparison of the results of power prediction and system real output indicates the good accuracy of proposed model.
KEYWORDS: wind turbine, output power, Adaptive Neuro-Fuzzy Inference System

1. INTRODUCTION

Generating electricity from wind is environmentally favorable, socially acceptable, and economically competitive. The power which is produced by wind has dominated other resources and has shown remarkable growth and dynamism in recent years. Technology of distributed products such as wind turbine, fuel cell, and photovoltaic energy will play an important role in human life in near future because of skyrocketing consumption of energy and pollution which is one of the main problems in the world today. Wind turbine as one of the most important sources of distributed production in power networks has a major share of power generation in present and more widely in future. One of the problems of using wind turbines is the indefinite rate of power generation by them; therefore, some tools are necessary to be available in order to predict the power of wind energy. In this paper, an adaptive neuro-fuzzy inference system has been used to make a model for predicting wind turbine power.

Several researches have been carried out on predicting the power of wind turbines. In section [1] the wind turbine power output is predicted when there are winds with low speed. The date resulted from turbine simulation is used and after appropriate parameters have been chosen, they have been divided and clustered to 2 to 5 clusters based on 5 scenarios. Then the neural network has been used to choose the most efficient scenario. The data of each cluster has been assessed by neural networks, ensemble neural networks, support vector machine, boosting and random forest techniques and for each cluster the method which has the best performance has been selected. The reason for choosing the mentioned methods in this research is to reduce calculation complexity and to increase the reliability. In part [2], the virtual model has been developed for short-term prediction of power output parameters and the rotor speed of wind turbine. To do so, data mining algorithms have been used and to develop the model, three phases have been considered including data preprocessing, model mining, and validating. Five parameters out of controllable, uncontrollable, and efficient parameters together with some amounts of past periods of those parameters were chosen to run the model. In this article, sampling has been done based on the wind speed and the data of 30 turbines have been used in two periods of time: one related to the time with low speed winds and the other related to the time with high speed winds. In order to predict the power output and the rotor speed the algorithms of random forest, neural network, boosting, support vector machine, generalized additive models and K algorithm of the closest neighbor have been used. The obtained results and their errors have been investigated and the neural network model had the best efficiency and was used for the virtual models for prediction of wind turbine parameters. The importance of the use of this method in terms of its generalizing capability for all kinds of turbines with different speeds of wind has been expressed by means of the data which have been used for training and testing the model. In part [3], a method has been introduced for the prediction of wind speed by means of generalized regression neural network modeling. Generalized regression neural network is a develop form of radial basis function networks which use real data for teaching the model and show that the mentioned method is superior to linear time-series models.

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In this article, first the data which are used are introduced in section 2 , then in section 3 the suggested method, adaptive neuro-fuzzy inference system improved by genetic algorithm is introduced and finally in part 4 the results of the application of this method on data will be presented.

2. Wind Farm Model and Data

Figure (1) shows a sample wind farm for implementing the model. This wind farm which is simulated in Matlab-Simulink software environment includes three 3-MW turbines with double fed induction generators [4].

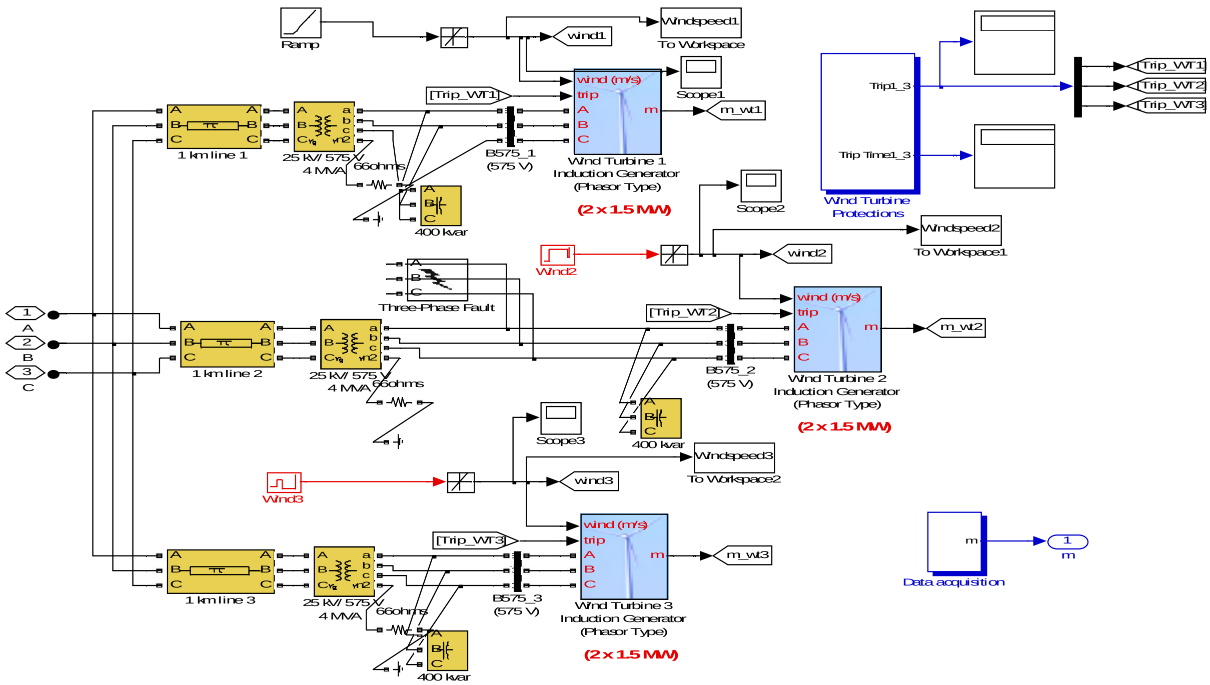
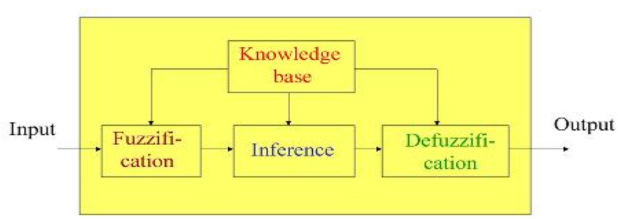


Figure 1. Simulated wind farm including three 3-MW turbines

3. Adaptive Neuro-Fuzzy Inference System

Adaptive neuro-fuzzy inference system was introduced by Jang in 1993 [5] and it is placed in the third category of the techniques of combining fuzzy system and neural network which is based on Sugeno fuzzy system. It is applied in function approximation and modeling and control and results in remarkable efficiency. Parameters of this network include the parameters of fuzzy if then rules, that is the front section parameters (membership functions) and the consequent parameters of Sugeno fuzzy rules. It has linkage learning parameters and uses gradient decent learning method and least square method. Fuzzy system parameters are considered and adjusted as neural network weights. In such systems as shown in figure (1), the system input is as a non-fuzzy number which should become fuzzy in the first step and then by means of knowledge base it is inferred and fuzzy output is generated. Finally, the system output should be non-fuzzy. Therefore, the fuzzy output should get defuzzification and should be identified as the system output [6].



Figure(2) : Fuzzy inference system

3.1. Genetic Algorithm

Genetic algorithm is an optimization technique based on biological evolution which could be useful for finding solutions to a large set of data in a short time. Each solution is offered by one chromosome. The, through the use of the operators of combination and genetic mutation, it tries to find the best chromosome in the shortest time. The best solution is picked up through a merit function which fits the objective function. In this way, a set of various solutions to a problem are examined and finally the best solution is selected.

General process of genetic algorithm is as the following;

1. Each solution is shown in the form of one chromosome
2. An objective function is picked up for evaluating the strength of chromosomes
3. Population initialization
4. Choosing operators of combination and mutation

3.2. Adaptive Neuro-Fuzzy Inference System Improved by Genetic Algorithm

The idea of combining genetic algorithm with adaptive neuro-fuzzy network in this paper is such a way that after teaching and updating the parameters of this network, by means of genetic algorithm, some other values are considered for those parameters and the best will be chosen. Number of teachable parameters varies depending on the kind and number of membership functions which are applied in constructing fuzzy inference system and also on the number of input variables. Each one of these parameters has been separately examined by means of genetic algorithm. To access optimized chromosome more quickly, values close the values determined by adaptive neuro-fuzzy network have been used in making initial chromosomes. Qualification criterion in selecting the superior chromosome is the values which reduce the square of errors. Figure (3) illustrates membership functions updated by genetic algorithm.

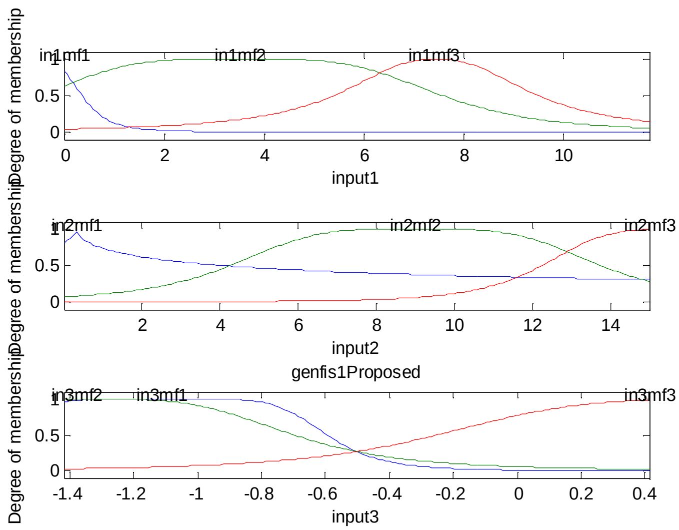


Figure (3): Membership functions updated by propose hybrid model

4. Proposed model and its Simulation Results

By means of the data obtained from the simulation of wind farm which includes three turbines, the proposed model was implemented on the data. The parameters which were considered at the model input included generator torque, blade pitch angle, wind speed and power output in two past times that is power output (t-1) and power output (t-2) and the model output was power output(t). To evaluate the proposed model two criteria of mean square error and mean absolute error were used. Equations 1 and 2 show how they are calculated:

Equation 1: $$MSE = \frac{\sum_{i=1}^{N}(y_i^* - y_i)^2}{N}$$

Equation 2: $$MAE = \frac{\sum_{i=1}^{N}|y_i^* - y_i|}{N}$$

The characteristics of generated network are shown in table 1.

Table 1: Characteristics of proposed fuzzy inference system

Number of nodes	78
Number of linear parameters	108
Number of nonlinear parameters	27
Total number of parameters	135
Number of training data pairs	2441
Number of checking data pairs	733
Number of fuzzy rules	27

In figure (4), the predicted output diagram and the favorable output of proposed model and the diagram of committed error are shown.

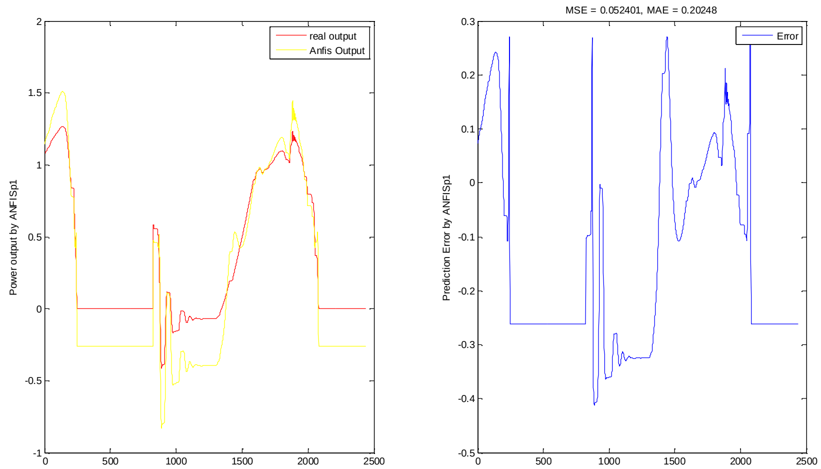


Figure 4: Prediction of power output by means of proposed hybrid model and the rate of error

By repeating the implementation of proposed hybrid model for ten times and calculating the mean errors, the mean square error as 0.0355 and the mean absolute error as 0.1541 were obtained.

Table 2: Error of prediction by means of ANFIS method improved by genetic algorithm

	MSE	MAE
ANFIS + GA	0.0355	0.1541

5. Conclusions

In this paper, a new model is presented for predicting the output power of wind turbines which uses the modified method of adaptive neuro-fuzzy inference system. This method has been used to improve fuzzy membership functions in neuro-fuzzy inference system by means of genetic algorithm. Generator torque, turbine blade angle, wind speed and power output in its two past time are defined as the system input and the system output is the predicted power output of turbine which is used to improve the practical adjustment of turbine blade angle. The rate of error indicates the good accuracy of proposed model.

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